

Cross-section Measurements with the Radioactive Isotope Accelerator (RIA)

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CROSS-SECTION MEASUREMENTS WITH THE RADIOACTIVE ISOTOPE ACCELERATOR (RIA)*

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RIA will produce beams of exotic nuclei of unprecedented luminosity. Preliminary studies of the feasibility of measuring cross-sections of interest to the science based stockpile stewardship (SBSS) program will be presented, and several experimental techniques will be discussed. Cross-section modeling attempts for the $A = 95$ mass region will be shown. In addition, several radioactive isotopes could be collected for target production or medical isotope purposes while the main in-beam experiments are running. The inclusion of a broad range mass analyzer (BRAMA) capability at RIA will enable more effective utilization of the facility, enabling the performance of multiple experiments at the same time. This option will be briefly discussed.

1. Introduction

Effective stewardship of the U.S. nuclear weapons stockpile requires a program based on deeper scientific understanding of the technical issues rather than the “trial-and-error” program prevalent during the underground testing era. This requirement is forcing us to examine all aspects of the Stockpile Stewardship Program (SSP) with renewed vigor and with the aim to improve our scientific understanding of the operation of a weapon. The nuclear cross-section networks used to model device performance are being re-examined to include “state-of-the-art” evaluated cross-sections; a combination of improved theoretically modeled cross-sections and evaluated experimental data, which wasn’t available when the cross-section sets were originally constructed. Many of the required cross-sections are for difficult or impossible to measure radioactive isotopes or isomers.

This paper focuses on several examples of cross-sections that could be measured, albeit in complex and difficult experiments, at the radioactive beam facility currently being discussed in the U.S., the Rare Isotope Accelerator (RIA).¹ RIA is envisioned as a luminous radioactive beam facility that is a hybrid of the projectile fragmentation (PF) method and the on-line isotope separator (ISOL) method. A simplified schematic of RIA is shown in Figure 1. The flexibility provided by having a source of higher energy projectile-like fragments from the PF method and lower energy target-like fragments from the ISOL method will enable such a facility to address a wide variety of physics issues and deliver beams spanning the extent of the chart of nuclides over a wide energy range. While the scientific basis for such a radioactive beam facility has been enunciated for decades², only recently has such a facility been considered as useful for SSP.

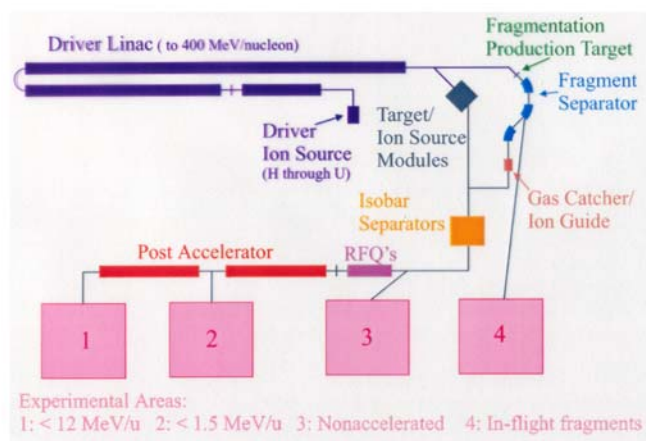


Figure 1. Simplified schematic layout of the RIA facility. Note that the isobar separator could include something like the BRAMA concept discussed in the text.

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Several classes of experiments are possible at RIA. Since production of radioactive isotopes, regardless of the method employed, is not limited to just one nuclide at a time, one obvious type of experiment involves the harvesting of radioactive isotopes, and subsequent chemical or isotopic purification for use as target material. Relevant SSP neutron-induced cross-sections could be measured with this harvested target material at a DT or DD neutron source located at RIA, a “white neutron” source such as WNR at LANSCE in Los Alamos, or following an irradiation at a reactor facility. Harvested isotopes would not be limited to those of interest to SSP, but would also include medically, astrophysically, environmentally, or chemically important isotopes.

A second type of experiment would involve the use of beams of isotopes of interest on surrogate neutron targets such as hydrogen, deuterium, helium, etc. Such cross-section measurements would help quantify parameters such as level densities and strength functions for input into models used to calculate $(n,2n)$ and (n,γ) cross-sections. These inverse reactions on surrogate materials would be an indirect method of obtaining cross-sections of interest to SSP radiochemistry.

The choice of performing an in-beam experiment versus harvesting target material for subsequent experiments is determined by the half-life of the isotope to be studied, resultant activities of the material following production, and the cross-section to be measured. The design of the experiment would vary depending on the target isotope, reaction to be studied, and produced activity. Determination of the cross-section might involve mass spectrometry and/or radioactive decay counting, and would rely on the decay properties of the final isotope to be assayed.

2. BRAMA

Because these experiments are likely to involve long beam times, optimization of RIA for multiple experiments running at the same time is essential. The Broad Range Atomic Mass Analyzer (BRAMA)³ concept for the ISOL method will need to be incorporated in some form to make RIA economically attractive and flexible. A possible design of such a flexible instrument is shown in Figure 2. The main features are a large dipole magnet separating each mass onto a focal plane in which individual masses can be extracted and sent to different experimental areas. Certain “mass spigots” could then be used for collection of target material, while others are used for in-beam experiments.

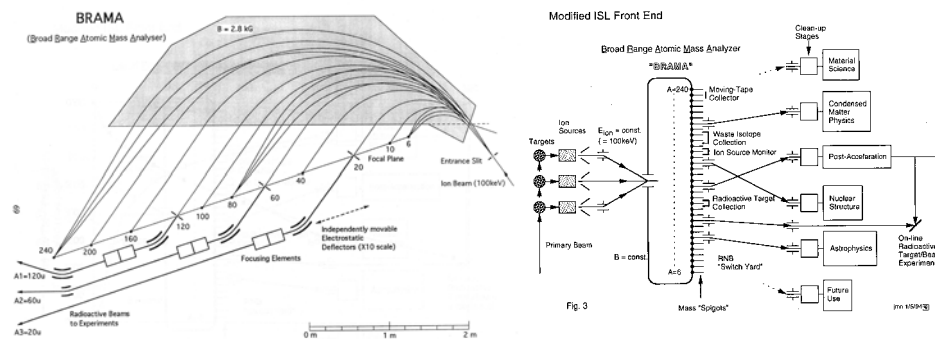


Figure 2. Schematic of the BRAMA separator. Note the multitasking capabilities of such an instrument.

3. Y/Zr Experiments

Y and Zr were sometimes positioned in a nuclear device to provide diagnostic information on its fusion performance in an underground test. Because core samples from a test would take days to be retrieved, the nuclides typically measured were $^{87,88}\text{Y}$ and $^{88,89}\text{Zr}$. A large cross-section network (as shown in Figure 3 for Y) was used in conjunction with a sophisticated computer model of the test to calculate $^{87}\text{Y}/^{88}\text{Y}$, $^{88}\text{Y}/^{89}\text{Y}$, $^{88}\text{Zr}/^{89}\text{Zr}$, and $^{89}\text{Zr}/^{90}\text{Zr}$ ratios to compare with the measured data. Much of the cross-section network is unmeasured and only calculated based on a reaction model and nuclear structure information. Historically, nuclear structure information for radioactive isotopes or isomers might be poorly known or completely unknown. Any measurement of a cross-section within these networks would be an improvement. Some estimates of important cross-sections, employing a $\Delta R/\Delta\sigma$ figure-of-merit, where ΔR is the change in a calculated ratio and $\Delta\sigma$ is the perturbation to the cross-section, were made. For the Y cross-section network, some obvious important cross-sections involving radioactive targets are $^{88}\text{Y}(n,2n)^{87\text{m3}}\text{Y}$, $^{87\text{m3}}\text{Y}(n,\gamma)^{88}\text{Y}$, $^{88}\text{Y}(n,2n)^{87}\text{Y}$ and the $^{88}\text{Y}(n,\gamma)^{89\text{m3}}\text{Y}$. Similarly, for Zr the $^{89}\text{Zr}(n,2n)^{88}\text{Zr}$, $^{89}\text{Zr}(n,\gamma)^{90\text{m4}}\text{Zr}$, $^{89}\text{Zr}(n,\gamma)^{90}\text{Zr}$ and $^{88}\text{Zr}(n,\gamma)^{89\text{m3}}\text{Zr}$ are important. Note the importance of isomeric levels.

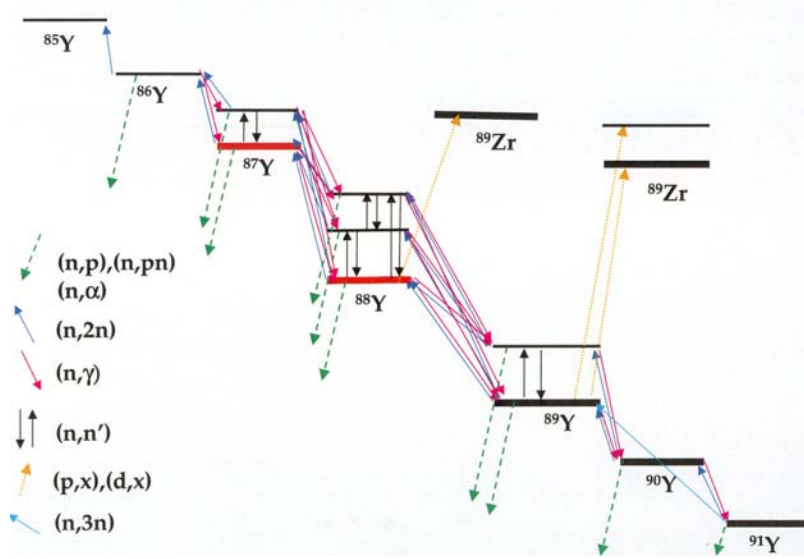


Figure 3. The Y cross-section network including charged particle reactions. The arrows indicate reaction cross-sections included over all relevant energies up to 20 MeV.

4. Fission Product Burnup

One of the isotopes measured which indicated the amount of fission that occurred during a nuclear test was ^{95}Zr . However, ^{95}Zr was not the nuclide present during the explosion—the long-lived precursor nuclides within the $A=95$ mass chain were. Any perturbation to the distribution of nuclides within the $A=95$ mass region (see Figure 4) due to subsequent neutron-induced reactions, especially those modifying the mass 95 chain yield, need to be determined.

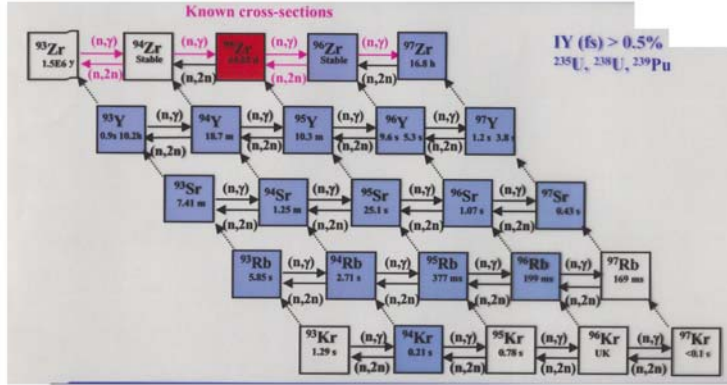


Figure 4. Mass 95 region of neutron-rich fission products.

STAPRE⁴ and ALICE⁵ calculations were performed on the $A=95$ nuclides shown in Figure 4 to generate a cross-section network for these neutron-rich nuclides. The $(n,2n)$ STAPRE calculations are shown in Figure 5. Note the fluctuating threshold and shape of the excitation function with this region. Since the relative cross-sections determine the amount of $A=96$ nuclides producing $A=95$ nuclides, and $A=95$ nuclides producing $A=94$, and since the cross-sections are not identical, it is likely that an improved cross-section set will improve the interpretation of the ^{95}Zr measured. Neutron capture cross-sections, as well as any other important neutron-induced cross-section (such as (n,p) or (n,α)) will be included in the cross-section set.

5. Conclusions

Identification of important unknown cross-sections for SSP has begun. Because neutron-induced reactions on radioactive isotopes and isomers are important, a radioactive beam facility such as RIA will play a crucial role in measuring these cross-sections. Such measurements will improve the prediction of isotope ratios and the estimation of fission product burnup. BRAMA may provide RIA an important multi-tasking capability because most experiments will require long beam times.

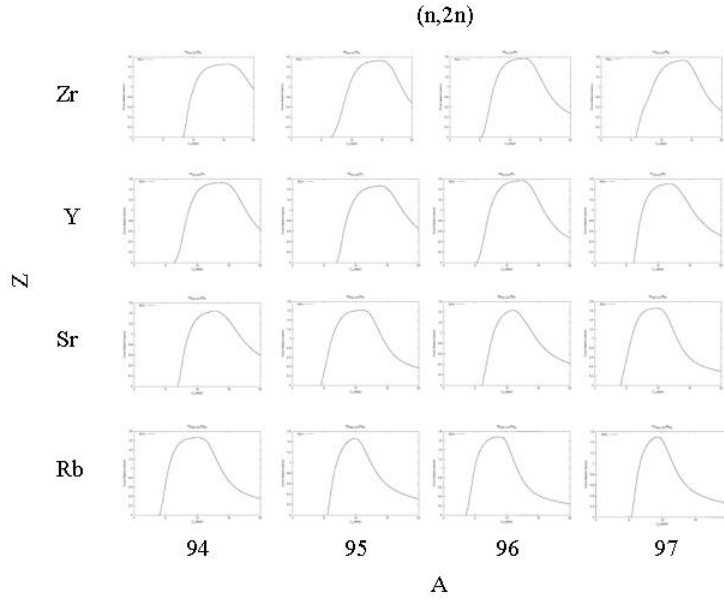


Figure 5. Results of STAPRE calculations for the A=95 region. All scales are the same with the y-axis from 0-1.8 barns and the x-axis from 0-20 MeV.

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References

1. ISOL Task Force Report to NSAC on Nov. 22, 1999 found at URL = <http://srfsrv.jlab.org/isol/ISOLTaskForceReport.pdf>.
2. Proceedings of 1st International Conference on Radioactive Nuclear Beams held in Berkeley, CA (1989), "ISL Research Opportunities with Radioactive Nuclear Beams" LALP 91-51 (1991), NUPECC Report on European Radioactive Beam Facilities (May 1993).
3. J. M. Nitschke Proceedings of the Workshop on Post Accelerator Issues at the ISL held in Berkeley, CA Oct. 27-29 (1993) 64.
4. M. Uhl and B. Strohmaier "STAPRE: A Computer Code for Particle Induced Activation Cross-sections and Related Quantities" Vienna report IRK 76/01 (1976).
5. M. Blann *Phys. Rev.* **C54**, 1341 (1996) and "Recent Progress and Current Status of Pre-equilibrium Reaction Theories and Computer Code ALICE" UCRL-97948 (1988).